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Enhancing the robustness of a national assessment of the marine environment

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ABSTRACT

The Australian government produces an independent report on the state of the Australian environment every five years. Based on 123 assessments of key pressures, key components of the marine environment, and the effectiveness of management responses to those pressures, the 2016 assessment identified that the overall state of the Australian marine environment can be regarded as good. However, the historical impacts of a number of pressures (e.g. commercial and recreational fishing) and ongoing pressures caused by activities currently inadequately managed (e.g. climate change and marine debris) have, and are continuing to, deteriorate its state. As a result, the outlook for the marine environment can be regarded as mixed. Addressing the challenges facing the marine environment will require a coordinated, collaborative and dedicated effort across jurisdictions and sectors. A number of improvements to the assessment framework were implemented for the 2016 report, the most substantial being the development of clear and repeatable processes for information synthesis and assessment. This improved transparency and supported the robustness of conclusions made. Improved communication of uncertainties associated with assessments, and comparability with assessments in previous reports has furthered the quality of the report and laid the foundation for improvements going forward. Processes that will continue to improve assessments include identifying key indicators that can be reliably and effectively monitored, improving data provision processes, enhancing assessment frameworks and reporting processes to ensure that approaches are integrated and support the delivery of tangible and practical risk mitigation and adaptation pathways.

1. Introduction

Under its *Environment Protection and Biodiversity Protection Act*, 1999 (EPBC Act) the Australian government is required to table an independent State of the Environment (SoE) report every 5 years (see https://soe.environment.gov.au). The overarching goals of the report are to provide the Australian government, decision makers and managers and the Australian public with authoritative information on the key national issues influencing and affecting the environment, the current state and recent trends in the environment and how effectively the environment is being managed in response to those issues. An outlook suggests likely upcoming issues that will need addressing.

This is no easy task. Scientists and other experts from around the country and/or their published data need to be accessed to provide information and assessments for nine different thematic chapters including the marine environment – the subject of this paper. Ideally, the SoE report would synthesize published open access information to provide trends in important environmental features and values over time and for significant examples, some indication of future trends or scenarios. However, apart from monitoring the physical environment and species directly targeted by commercial fisheries, time series for Australia's extensive marine environment are generally limited in number and spatio-temporal cover. The availability and quality of information that may be used to support SoE reporting lies on a spectrum from: (i) high quality, extensive or long term datasets (e.g. marine protected area monitoring (e.g. [51]) and a number of long term reef monitoring programmes (e.g. [20])); (ii) moderate quality time series of data of varying lengths (e.g. continuous plankton recorder data (e.g. [66]), fisheries surveys (e.g. [68])); (iii) low quality data of a sporadic nature (e.g. anecdotal or incidental information (e.g. [64])) to (iv) expert opinion associated with no empirical observations.

In order to provide a comprehensive and informative assessment of

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the marine environment that can be built on in future years, a repeatable and clearly articulated process for identifying, utilising and merging data of varying quality and from different sources to form a national perspective is required. This process should also acknowledge the uncertainty associated with both the information used and the ensuing interpretation of that information. Inclusion of this uncertainty thereby provides key information on the extent to which available data is representative of the environmental indicator or feature in question [32]. As the extent to which the empirical observations accurately represent the state of the component of the environment in both space and time diminishes, so the reliance on expert opinion increases, forming a spectrum reflecting the influence of direct measurements of the environment and diffuse expert knowledge.

There is therefore a tension between providing a statistically robust report that is based exclusively on spatially representative, validated time series data and a sufficiently comprehensive report that will meet the overall objectives of the reporting framework, including its target audience, which in this case is broad. Earlier SoE reports fluctuated between being scientifically robust but limited, and opinion-based, but comprehensive. Recent reviews of the SoE [81] emphasize the need to provide continuity in the reporting process. Given the current limited state of knowledge on Australia's marine environment, delivering this continuity requires the report to be based to a large extent on expert advice and interpretation of a diverse set of information. It also provides the opportunity to identify the information with important consequences for which little empirical data are available.

In this paper, the approach taken for reporting on Australia's marine environment for this most recent reporting cycle [26] is described and compared to that taken in the previous cycle. In particular, an approach to use and store expert advice, leading to a more robust and replicable synthesis and an evaluation of the confidence level and coherence between available data and expert opinion is described. Processes that have and will continue to improve assessments of the marine environment into the future and enhance the comparability of expert advice between five-yearly assessments, the lack of which is a common failing in using expert advice in ongoing environmental reporting processes are discussed. To provide context for these developments, an overview of the assessment of the marine environment is firstly provided.

1.1. The Australian marine environment

At 13.86 million square kilometres, Australia's marine environment is the third-largest marine jurisdiction in the world (Symonds et al., 2009). It is home to a diverse array of marine species including marine mammals and reptiles, more than 4000 species of fish, and tens of thousands of species of invertebrates, plants and microorganisms [12]. Australia's marine environment is an important asset to the community; more than 80% of the Australian population live within 50 km of the ocean [1], with population growth fastest near the coast (Clarke and Johnson, 2017) [14]. Australia's marine environment is used for a wide range of recreational activities and is also an essential part of Aboriginal and Torres Strait Islander peoples' cultures, customs and traditions.

Species in the Australian marine environment support commercial fisheries and aquaculture worth $2.7 billion in 2014–15 [76]. The economic value of mining and energy resources extracted from the Australian marine environment is expected to more than double from $32 billion in 2012–13 to $67 billion by 2029–30 [6]. Overall, in 2013–14 marine industries were estimated to have contributed $73.1 billion to the Australian economy with near term growth estimated at 4.4% per annum [2]. Australian species and natural marine treasures—such as the Great Barrier Reef in Queensland, Lord Howe Island in New South Wales, the Great Australian Bight in South Australia and Ningaloo Reef in Western Australia—stand as icons of Australia's national identity and support important revenue from marine tourism. Importantly, the oceans and coasts provide a further $25 billion worth of essential ecosystem services, such as carbon dioxide absorption, nutrient cycling and coastal protection [24,56]. Benefiting from the value of the marine environment requires effective management, including conservation, and the sustainable use of the environment and living resources.

2. Structure of the report

Within each five year cycle of assessments of the state of the environment, each SoE report produced builds on the foundations of previous reports, in a spirit of continual improvement and with an overall aim of achieving a robust and defendable technical information base for the findings of the report. For this five year SoE report cycle, an emphasis was to build on the foundation of the previous cycle to improve the information on identifiable trends. The SoE report was published in early 2017, covering a reporting period of 2011–2016 [40].

The entire report is divided into nine thematic chapters representing biogeographic or conceptual aspects of the Australian environment and includes: the Antarctic environment, atmosphere, biodiversity, built environment, coasts, heritage, inland waters, land, and marine environment. Each chapter contains detailed discussions of the pressures, state and trends, management effectiveness, resilience, risks and outlook relating to the environment in that theme. In reporting on these matters, the report refrains from making recommendations on policy responses, thereby generating an independent perspective on environmental performance without constraining management or policy responses that might result from issues identified in the report.

All thematic reports for the 2016 SoE report followed a structure developed for the 2011 SoE report (State of the Environment 2011 Committee 2011; see https://soe.environment.gov.au). The driving forces-pressures-state-impacts-responses (DPSIR) framework [71], which has been used internationally for environmental assessments (e.g. [5,53,8]), provided a common overall structure across themes. It also provided for direct comparisons between the 2011 and 2016 reports, at least where data preparation methods were comparable (see [39] for an overview of the approach to the overall report and the nine thematic chapters). Assessments of pressures on the environment, environmental state and recent trends and management responses to identified pressures were summarised in written and graphical formats, allowing for rapid comparison of information between the reports (Fig. 1).

Summaries associated with assessments comprised one of four grades according to, in the case of pressures, the perceived level of impact (very low impact, low impact, high impact, very high impact), in the case of the state of components, the perceived condition (very good, good, poor, very poor) and in the case of management activity, the perceived effectiveness (very effective, effective, partially effective, ineffective) related to six elements: understanding, planning, inputs processes, outputs and outcomes. These six elements were based on an evaluation framework initially established by the International Union for Conservation of Nature's World Commission on Protected Areas [35–37]. Summaries also provided a scale of four grades of measured or perceived trend over time (improving, stable, deteriorating, unclear).

For the 2016 SoE report, substantial effort was placed into providing easy access to the findings of the nine thematic chapters via a digital platform (see https://soe.environment.gov.au).

2.1. Reviews and corroboration of expert knowledge

Content of each of the thematic reports went through two formal review processes. The first was focused on the overall scope of content in each report and carried out by national, state and territory government agencies and regulators. The second was focused on review of specific content and its representativeness of current knowledge, understanding and processes. The second review involved firstly national, state and territory government agencies and regulators and secondly two experts from the scientific community. The expert reviewers were

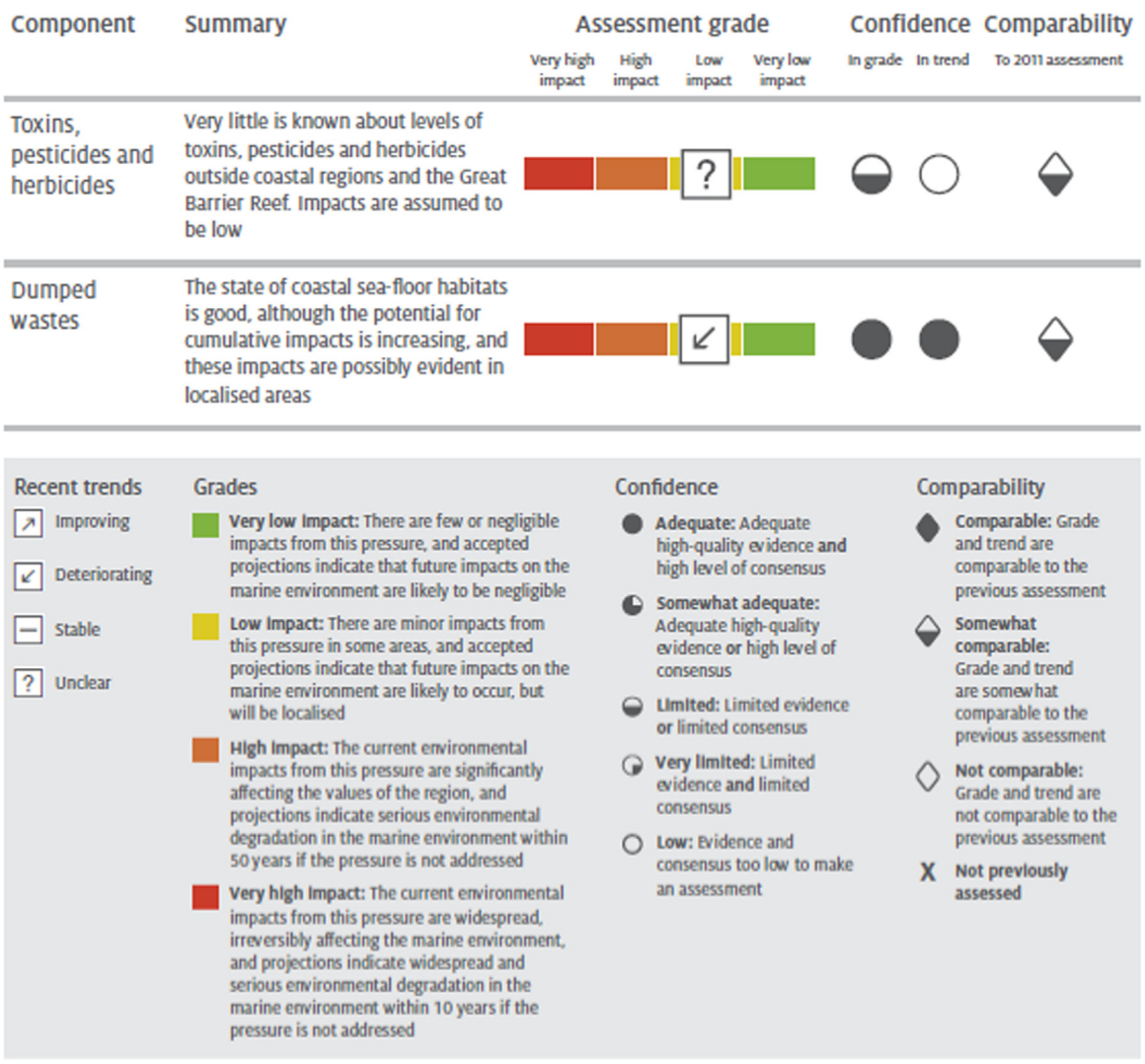
Component
Summary
Assessment grade
Very high impact
High impact
Low impact
Very low impact
Confidence
In grade
In trend
Comparability
To 2011 assessment
Toxins, pesticides and herbicides
Very little is known about levels of toxins, pesticides and herbicides outside coastal regions and the Great Barrier Reef. Impacts are assumed to be low
Dumped wastes
The state of coastal sea-floor habitats is good, although the potential for cumulative impacts is increasing, and these impacts are possibly evident in localised areas
Recent trends
Improving
Deteriorating
Stable
Unclear
Grades
Very low impact: There are few or negligible impacts from this pressure, and accepted projections indicate that future impacts on the marine environment are likely to be negligible
Low impact: There are minor impacts from this pressure in some areas, and accepted projections indicate that future impacts on the marine environment are likely to occur, but will be localised
High impact: The current environmental impacts from this pressure are significantly affecting the values of the region, and projections indicate serious environmental degradation in the marine environment within 50 years if the pressure is not addressed
Very high impact: The current environmental impacts from this pressure are widespread, irreversibly affecting the marine environment, and projections indicate widespread and serious environmental degradation in the marine environment within 10 years if the pressure is not addressed
Confidence
Adequate: Adequate high-quality evidence and high level of consensus
Somewhat adequate: Adequate high-quality evidence or high level of consensus
Limited: Limited evidence or limited consensus
Very limited: Limited evidence and limited consensus
Low: Evidence and consensus too low to make an assessment
Comparability
Comparable: Grade and trend are comparable to the previous assessment
Somewhat comparable: Grade and trend are somewhat comparable to the previous assessment
Not comparable: Grade and trend are not comparable to the previous assessment
X Not previously assessed

Fig. 1. Example of the assessment summary for the pressures associated with 'Toxins, pesticides and herbicides' and 'Dumped wastes'.

selected on the basis of their relevant expertise to each report. Reviewers were asked by the coordinating committee for the report to provide an anonymous and objective assessment of each report, identifying omissions of relevant data or analyses, and issues with methodology, clarity or objectiveness.

2.2. Approach of the 2016 marine environment report

Implemented for the first time in the 2011 SoE report, a separate thematic chapter on coastal environments was included in the SoE report, although at the time was considered to be rudimentary and not a comprehensive assessment of Australia's coastal environments. This thematic chapter was further developed in the 2016 SoE to include formal assessments spanning socio-economic and ecological components of Australia's coastal environment [14]. Recognising the connectivity between the coast and marine environments and potential overlaps and synergies between the two thematic chapters, considerable effort was placed into ensuring datasets and information used were complimentary across the two thematic chapters. While some division of what might be included in the coastal and marine environment thematic chapters could be considered arbitrary, regular cross-referencing between the two chapters ensured that linkages between reporting on the environment were clear. Given the comprehensive nature of both reports, the many separate issues each contains and the varying approaches to thematic chapters, only the content of the marine environment thematic chapter will be presented here.

Recognised experts or expert teams in specific discipline areas were tasked with developing and carrying out assessments. Each assessment was guided by a standardised reporting template and then independently reviewed by expert peers, with assessments updated and revised in light of reviews received. Given the diversity of components of the marine environment assessed, variability in the spatio-temporal coverage of associated datasets and the diversity of methods used to collect datasets, assessments varied from being data deficient and therefore qualitative and based on expert opinion (e.g. sea snakes, sharks and rays) to statistical assessment of datasets from a small number of 'representative' locations or species (e.g. inshore reef fish) to modelling approaches of comprehensive national scale datasets (e.g. satellite derived sea surface temperatures). Around 150 experts were involved in the assessments and reviews, with many assessments including new analyses of available data carried out specifically for the 2016 SoE report.

In total, 123 assessments across pressures, current state and trends and management effectiveness were included in the 2016 marine environment report. Because of the variability in datasets and information available to support individual assessments, robust reporting of the marine environment at the national scale was often not possible. Where assumptions were made in order to provide an evaluation at the national level, these were articulated and reflected in uncertainty measures associated with each assessment.

Metadata records of sources and methods used in assessments were produced and made publicly available through the Australian Ocean Data Network (AODN).[1] Each metadata record housed on the AODN provides a direct link to each assessment, thereby providing clear information on the data, methods and rigour of the assessment, thereby providing for reproduction of assessments.

3. The 2016 marine environment assessment – brief summary of findings

3.1. Pressures

Australia's marine environment is subject to many varied pressures arising from the main drivers of environmental change, that is, human population growth, distribution and composition and associated economic activity [40]. It is also influenced by natural phenomena including the El Niño–Southern Oscillation, the Indian Ocean Dipole and the Southern Annular Mode.

Several activities that have previously been identified as placing high levels of pressure and impacting components and/or regions of the marine environment such as commercial fishing and oil and gas exploration, are now decreasing because of economic pressures and management frameworks put in place to ensure future sustainability and environmental protection (see [60,57]). Pressures associated with climate change continue to increase. The 2016 SoE report identified that climate extremes, where simultaneous strong phases of climatic phenomena occur and interact with climate change, have led to widespread substantively higher water temperatures across 2011–2016 (see Fig. 2) and resulted in impacts on marine habitats, communities and species. One of the strongest recorded La Niña events in 2010–12, superimposed on overall increasing water temperatures associated with climate change, led to widespread bleaching of corals, loss of kelp forests, fish and invertebrate deaths and changes in species distribution in western Australian marine environments [61,62,84]. In 2015–16, the strongest El Niño event since 1998 superimposed on overall increasing water temperatures associated with climate change affected northern and eastern environments, also resulting in widespread bleaching of corals [3].

Pressures associated with marine debris continue to increase with high, but variable, concentrations of land- and ocean-sourced marine debris found in all marine environments [41,65]. Significant quantities of plastics have and continue to be reported in the digestive tracts of several species of marine vertebrates (e.g. [47]). Since 2011, there has been an increase in most forms of vessel activity in Australian marine waters ([10]; Fig. 3). Improvements to the management of commercial vessels have resulted in mitigation and minimisation of some of the pressures associated with this sector of vessel activity, but the impacts and associated trends of some pressures, particularly those that are not currently managed across all forms of vessels (e.g. anchor scouring, vessel strike of marine animals and introduction of foreign marine species to the Australian marine environment through the exchange of ballast water and biofouling; [18,19]) are largely unknown. Increasing use of the marine environment is shifting anthropogenic contributions to marine soundscapes from high point source acute contributions (e.g. seismic surveys, pile driving) towards ongoing low-level noise (vessel activity, marine renewable energy) with uncertain long-term chronic impacts on the Australian marine environment.

3.2. Current state of the environment and recent trends

Information on the current state and recent trends of the biological and ecological components of Australia's marine environment is highly variable across Australia's marine estate and is often inadequate for robust assessment. Of those habitats, communities and species groups for which there are time series available, many are in good condition (e.g. mesopelagic and epipelagic fish species) or improving from historical impacts (e.g. some pinniped and cetacean species, benthic communities on the shelf and slope; [55,69,63,70]). Trends in some species are highly spatially variable, with individuals in some regions in good condition and stable, and those in other regions in poor condition and deteriorating (e.g. inner shelf reef species; Fig. 4; habitats and communities of the Great Barrier Reef [20,29]).

Large canopy-forming seaweeds are still prevalent in many locations around Australia, but increased water temperatures and range extension by the sea urchin *Centrostephanus rodgersii* in south-eastern Australia has led to the loss and overgrazing of kelp beds in temperate rocky reefs, resulting in a poor and deteriorating state and trend for this habitat [42]. As a result of this deteriorating state, giant kelp forests across south-east Australia were the first marine community to be listed as a threatened ecological community under the EPBC Act in 2012.

A number of individual species and habitats remain in poor condition or are declining because of cumulative impacts associated with high mortality from bycatch within fisheries, including those in areas adjacent to and beyond Australia's marine estate, impacts on nesting/breeding sites associated with coastal development, habitat degradation, feral species and climate change (e.g. flesh-footed shearwater (*Puffinus carneipes*), Australian sea lions (*Neophoca cinerea*), north Queensland hawksbill turtles *(Eretmochelys imbricata),* some demersal shark species; see [29,27,28,46]).

A number of changes to biological and ecological processes have occurred. Observed reductions in primary and secondary productivity primarily in waters north of 35°S are considered to be associated with reduced nutrient supply associated with ocean warming [78]. Areas of increasing primary productivity primarily located along the eastern seaboard of Australia are potentially being driven by increased eddy activity and southwards extension of eddies associated with the Eastern Australian Current [43]. Changes to ocean currents have affected connectivity within marine ecosystems as observed through shifts in species distributions, especially in south-eastern Australia (e.g. [33,45]). There has been trophic (food chain) restructuring of some ecosystems as a result of commercial and recreational fishing, pollution, introduction of foreign species, and habitat modification (e.g. [44,48]). Some of these changes are irreversible, but the effects are generally unknown.

Although the populations of at least one marine species have increased to the point that it could be delisted (see [9]), no marine species have been removed from the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) threatened species list since 2011. Eight species and one ecological community have been added, including two sea snake, two seabird, two shark, one sawfish and one fish species. A further two fish species have been upgraded in their classifications under the EPBC Act to critically endangered.

3.3. Management effectiveness

Several improvements to management frameworks across Australian Government and state and territory jurisdictions, including the implementation of new national regulators since the 2011 report (e.g. the implementation of the National Offshore Petroleum Safety and Environmental Management Authority established in 2012, the implementation of Harvest Strategies in Commonwealth fisheries), have provided beneficial outcomes for the marine environment. Continued expansion of marine protected areas across Australian Government and state and territory jurisdictions (Table 1) has also meant that an increasing proportion of the marine environment has been formally placed under active conservation management plans. These improvements to management frameworks have directly reduced pressures caused by the activity and/or the likelihood of impacts associated with the activity occurring. Several strategies focused on conservation and

[1] www.catalogue.aodn.org.au/geonetwork/srv/en/metadata.show?uuid=436e580e-ff33-4d15-a39c-b04c7d65083c.

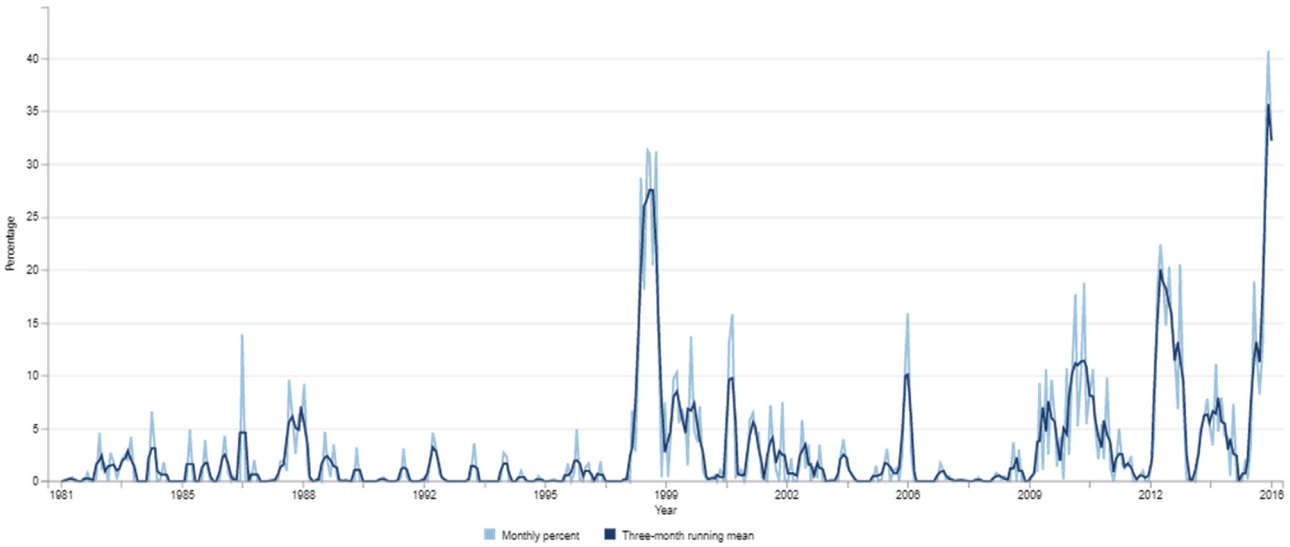

Fig. 2. Percentage of the Australian exclusive economic zone experiencing extreme sea surface temperatures, 1981–2016. Extreme sea surface temperatures (SSTs) were calculated by comparing monthly SSTs with all other recorded monthly SSTs in the time series at a particular grid point. If the SST was higher than all other SSTs recorded for that grid point during that month, it was considered an extreme event.

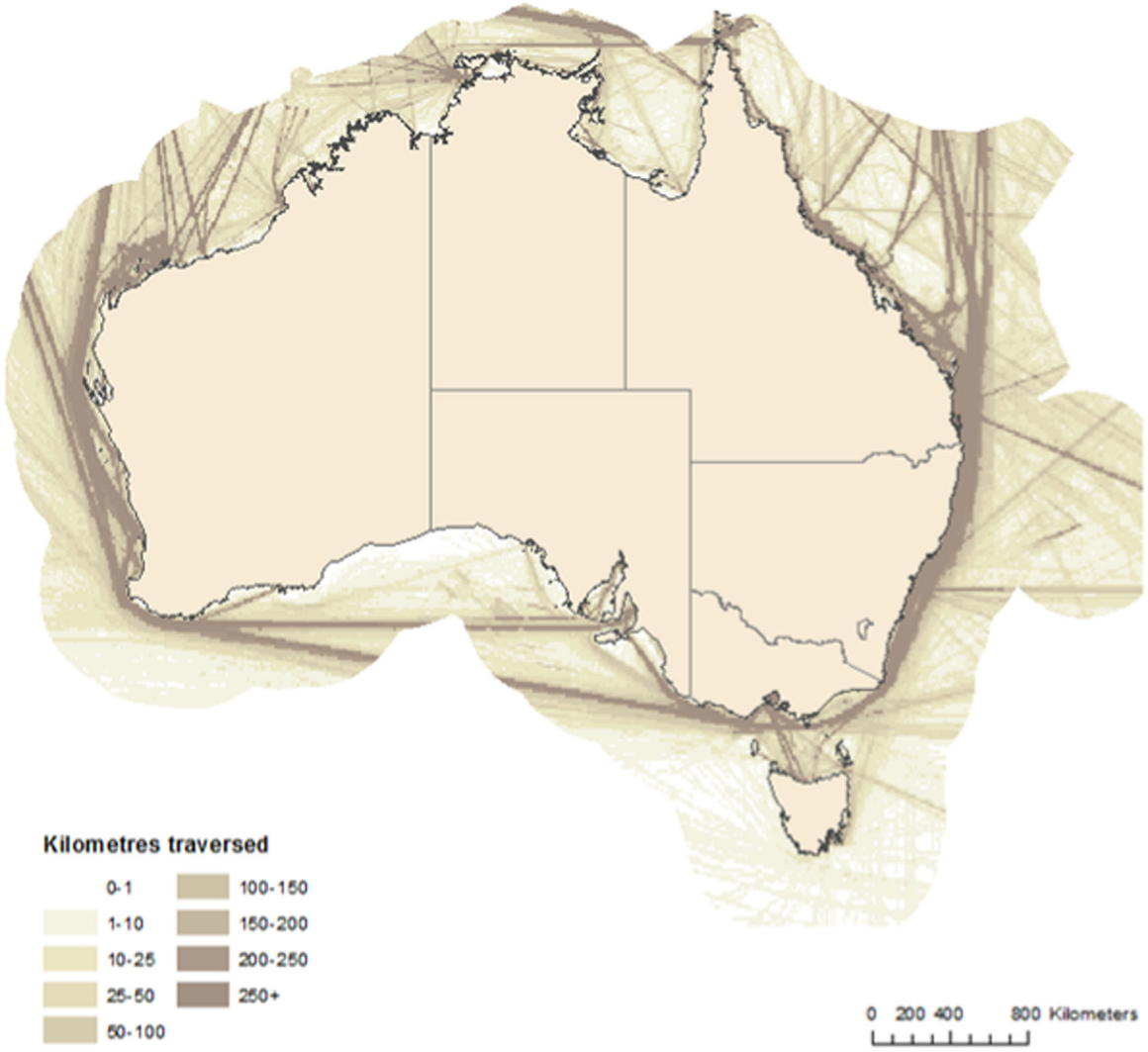

Fig. 3. Density (kilometres traversed) of vessels more than 24 m long in the Australian exclusive economic zone.

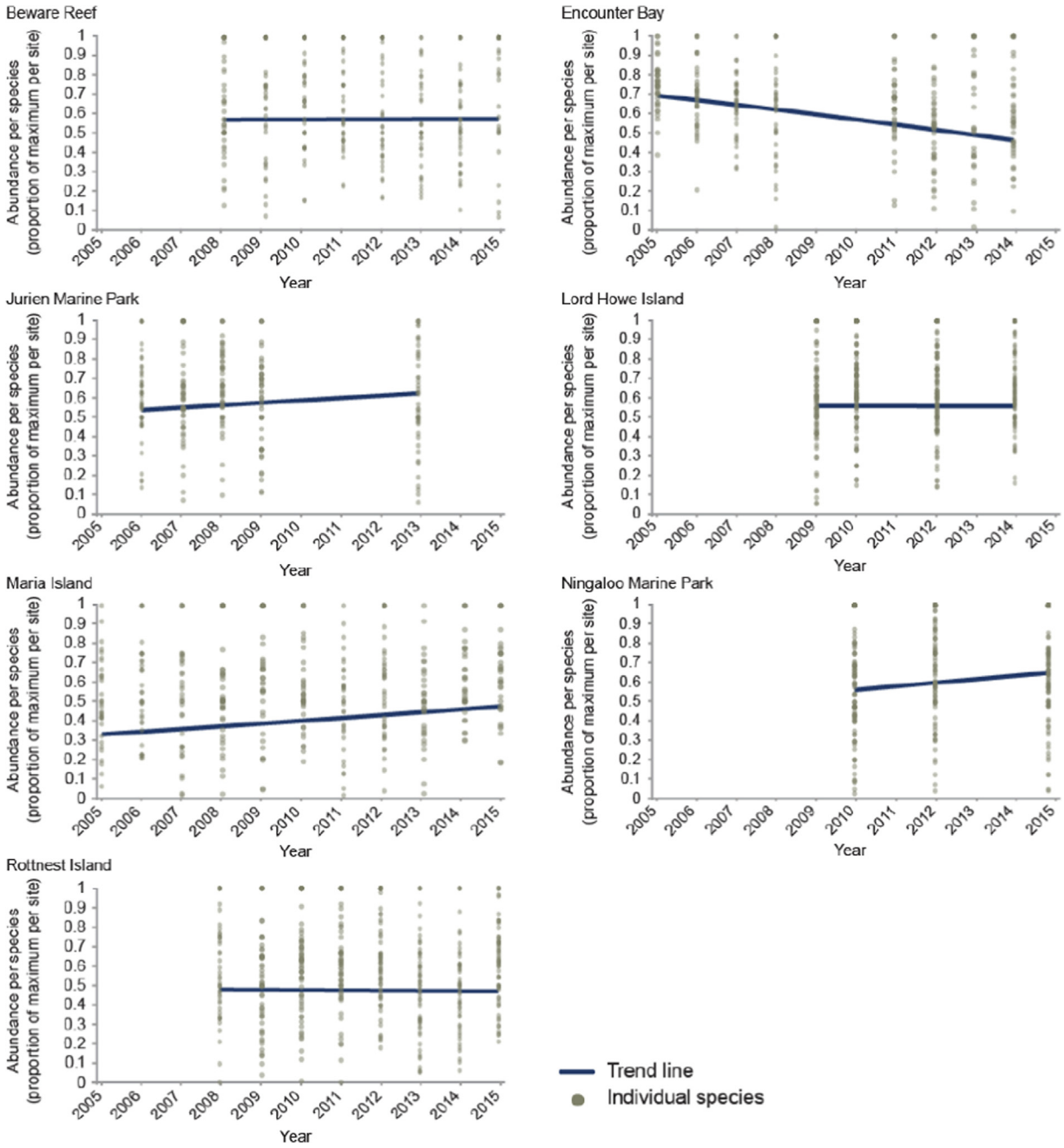

Fig. 4. Trends in the abundance of reef fish at long-term reef biodiversity monitoring locations around Australia. Trends were significant ($p < 0.05$) at Encounter Bay (b = -0.107), Jurien Marine Park ($b = 0.050$), Maria Island ($b = 0.061$) and Ningaloo Marine Park ($b = 0.075$).

biodiversity protection, and sustainable development of Australia's environment have been released, providing frameworks for the co-ordination of management of the marine environment across State, Territory and Australian Government jurisdictions (e.g. [58,74,4,56]).

Industry driven changes to activities in response to community perceptions, often termed 'social licence to operate' (SLO) is becoming more prominent across sectors. There has been a shift towards government regulation of company–community interactions and incorporation of SLOs into environmental licensing systems [66]. Many commercial fisheries are now adopting third-party certification schemes through independent bodies such as the Marine Stewardship Council and the Aquaculture Stewardship Council (e.g. see http://www.fish.wa.gov.au/About-Us/Publications/Marine_Stewardship_Council/Pages/default.aspx). Both international councils facilitate independent reviews of fisheries and aquaculture operations for their sustainability and traceability of product, setting standards that operations must meet on both aspects to be certified. Research in measuring and modelling SLOs is expanding, with the aims of guiding industry in developing trust-based relationships with community stakeholders and implementing frameworks for operations that uphold that trust [54].

The 2016 report, similarly to the 2011 report identifies that management activities focused on pressures associated with climate change and marine debris continue to be the least effective. Although a number of products have been developed for use in identifying processes likely to cause impacts[2]; these are relatively few and the explicit incorporation of pressures and risks associated with and impact mitigation in

[2] See, for example, www.bom.gov.au/oceanography/oceantemp/GBR_SST.

Table 1
Area of Australia's marine parks and reserves (km2) by IUCN management category as reported in the 2014 Collaborative Australian Protected Area Database.

IUCN category	Australian Government	NT	QLD	NSW	VIC	TAS	SA	WA	Total
IA	2122	–	411	–	21	1	3127	3126	8808
IB	–	–	–	–	–	–	–	–	–
II	1,075,760	–	16,607	666	533	328	3100	8754	1,105,748
III	–	–	–	–	109	–	7	631	745
IV	579,548	–	8996	1688	–	13	15,199	4181	609,625
V	4326	–	–	–	–	47	–	–	4373
VI	1,287,733	2909	17,697	1134	681	179	8318	11,543	1,330,194
Total	**2,949,489**	**2909**	**43,711**	**3488**	**1344**	**568**	**29,751**	**28,235**	**3,059,493**
% of total jurisdictional area	**40.59**	**4.05**	**35.83**	**39.63**	**13.16**	**2.54**	**49.56**	**24.40**	**39.85**

NT = Northern Territory; QLD = Queensland; NSW = New South Wales; VIC = Victoria; TAS = Tasmania; SA = South Australia; WA = Western Australia. Note that the table does not include the reserves or that area of the Exclusive Economic Zone (EEZ) surrounding Macquarie Island (reserves: 162,756 km^2, EEZ: 471,837 km^2), Heard Island and McDonald Islands (reserve: 70,953 km^2, EEZ: 410,722 km^2). The table does not include marine Indigenous Protected Areas as they are currently not listed in the Collaborative Australian Protected Area Database. The area of the Australian Government marine parks and reserves includes the Great Barrier Reef Marine Park, of which approximately 77,329 km^2 is within Queensland state waters. It also includes those parts of the National Representative System of Marine Protected Area for which management plans are yet to be implemented. The area of the Queensland marine parks and reserves includes a portion that are in Commonwealth waters, the majority associated with the Great Barrier Reef Coast Marine Park (approximately 13,600 km^2). Marine areas were derived from the Maritime Boundaries Program, Geoscience Australia. Areas have been rounded to the nearest kilometre. Collaborative Australian Protected Area Database: www.environment.gov.au/land/nrs/science/capad.

response to climate variability and change into most management frameworks is currently lacking. This is because of, at least in part, the complexity of responses of the marine environment to climate variability and change [16,17]. Current assessments of management frameworks in place and their ability to contribute to global efforts in addressing climate change vary and many frameworks may need to be redesigned to meet currently agreed and any additional targets Australia might commit to in the future (e.g. [85]).

The Australian Government recognises marine debris as a key threatening process under the EPBC Act since 2003. A threat abatement plan was developed in association with the listing [21], with the first review of the achievements against the objectives of the plan conducted in 2015 [23]. Based on measurements against two key criteria, it was concluded that although significant progress on parts of the plan had been made, the key threatening process being addressed by the plan had not been abated and the objectives of the plan not met. A revised plan updating the objectives and associated actions required and covering another five years is currently being developed.

3.4. Outlook

The outlook for the marine environment, given the current pressures and management frameworks in place to mitigate those pressures, is identified by the 2016 report as clearly mixed. Although overall status for the more frequently studied habitats, communities or species groups may be able to ascertained, trends in many and, in particular, many species listed under the EPBC Act and subject to associated recovery plans, are unclear. This limits our capacity to identify what management responses would benefit these species, and therefore hypothesise on what the future might look like for the marine environment. Seabed environments and associated demersal and benthopelagic species groups across shelf and slope regions are expected to continue to recover in response to reduced fishing pressures. Those habitats and species expected to continue to deteriorate into the future include coral reefs, fringing reefs and algal beds, reef fishes and Australian sea lions with many declines in the habitats communities and species of the marine environment largely associated with increasing pressures caused by climate change.

The variety of marine planning by Australian jurisdictions leads to a complex spatial management structure. For example, some areas can be subject to specific fishery zoning and spatial biodiversity management plans, while also encompassing oil leases, oil wells, vessel activity, commercial fishing and other marine uses (e.g. Fig. 5). These are all managed independently of each other and, in some cases, are managed separately and independently across Commonwealth, State and Territory jurisdictions. While horizontal integration of management may occur (i.e. across differing jurisdictions/levels of government), vertical integration (i.e. across sectors) is largely lacking.

Truly integrated management of the marine environment should bring the principles of ecosystem-based management, sea-use management and marine spatial planning into one framework. This framework should allow for the multiple uses of the marine environment, while ensuring that ecosystem structure, functioning and services are maintained, and that safeguards are in place to protect components of marine ecosystems (Ehler and Douvere [25] ; see also [38] for a discussion of policy frameworks supporting integrated management). The reality is that ecosystem-based and integrated management mean different things to different people and different sectors. As a result, uptake of integrated approaches to the management of marine natural resources has been slow and although approaches such as ecosystem-based management may have been adopted at a policy level, practical implementation has been generally limited [73]. Tight resource constraints also have a major impact on the capacity of jurisdictions to implement what has been identified as best practice and aspirational. This will be a constraining factor into the foreseeable future for integration of management of marine activities.

Similarly definitions and terminology used when identifying and discussing risks and the responses or resilience of marine ecosystems to those risks (including impacts) vary. Further, assessment frameworks vary greatly range from best judgement through to a range of quantitative approaches. Even within relatively restricted single sector domains there is no single agreed approach (e.g. [7,83,86]). This results in patchy use of risk assessment for managing marine resource and variability in the prioritisation of limited resources and actions, including environmental monitoring, associated processes in implementation, and addressing of cumulative impacts. Addressing challenges for the marine environment as we look to the future will require a coordinated, collaborative and dedicated effort involving researchers, government, industry and the Australian community.

4. Enhancements to the marine environment assessment in 2016

The approach incorporated into the 2016 marine environment report built on that developed for the 2011 SoE report [82]. In 2011, assessments were the output of regional workshops where relatively small numbers of attendees with expertise in defined domains were tasked with estimating grade and trend across the many varied aspects of the marine environment associated with the identified indicators,

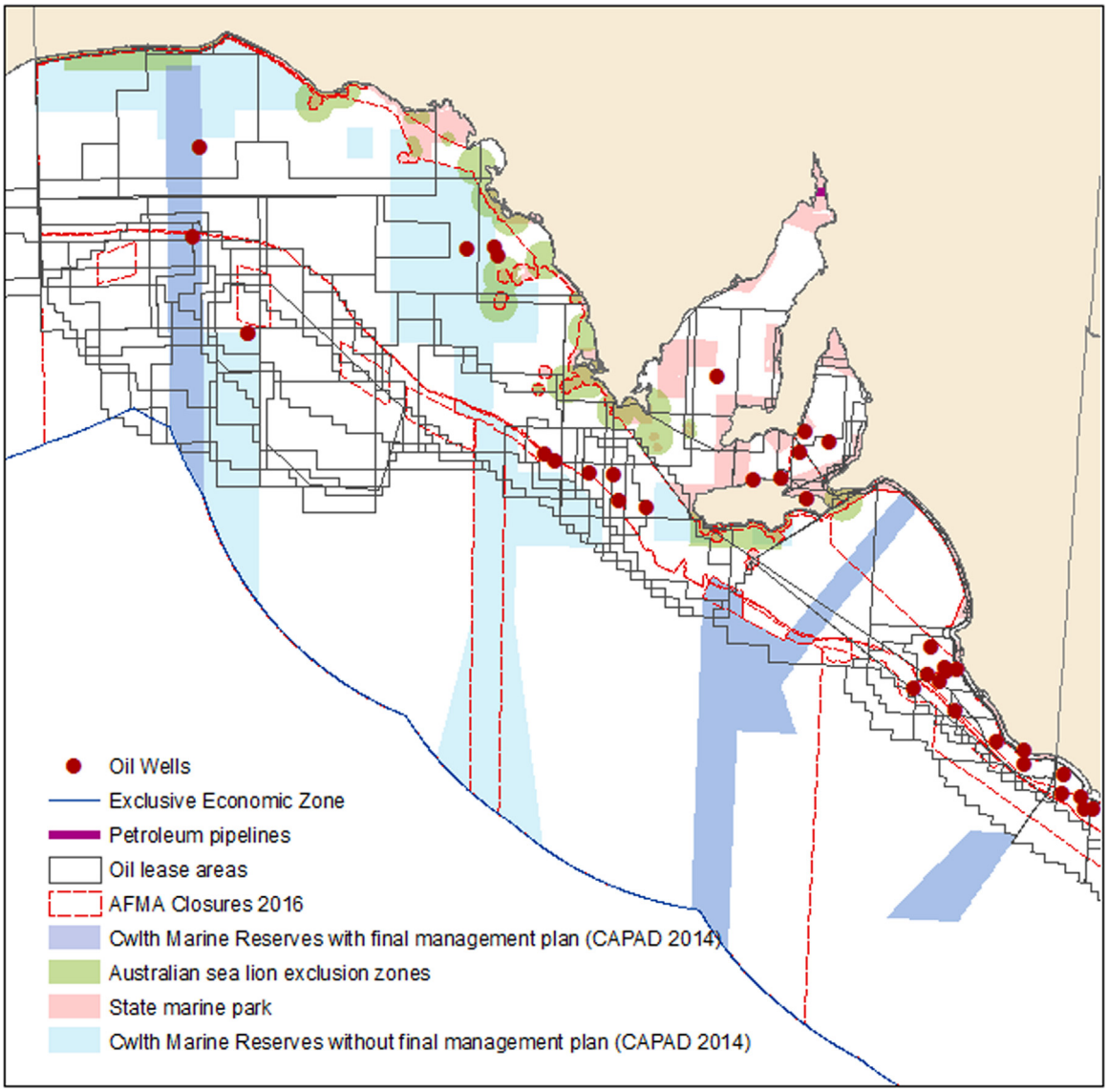
Oil Wells
Exclusive Economic Zone
Petroleum pipelines
Oil lease areas
AFMA Closures 2016
Cwlth Marine Reserves with final management plan (CAPAD 2014)
Australian sea lion exclusion zones
State marine park
Cwlth Marine Reserves without final management plan (CAPAD 2014)

Fig. 5. Example of marine spatial management in the Great Australian Bight off South Australia by multiple sectors and jurisdictions.

aspects for which attendees often had little or no expertise. While expert elicitation can be a powerful tool for providing judgements under constrained resources and where data are inadequate or extrapolations are required, their performance relies on the relevance of the expertise of the group and adequate cross examination of judgements and reasoning in order to quantify uncertainty and bias in the elicited information [11,59,75]. To ensure that use of expert opinion was appropriately applied to assessments in the 2016 marine environment report, firstly recognised experts or expert teams were targeted and tasked with carrying out assessments and secondly all assessments were peer reviewed by additional experts in the relevant scientific domain. This maximised the rigour associated with the use of expert opinion and with the generation of metadata records from each assessment housed on the Australian Ocean Data Network, ensured that the information and approaches used to form that expert opinion was documented. By developing such a process, a pathway on which approaches, datasets, methods and analyses can be built on and reproduced in future State of the Environment reports now exists. This will facilitate directly comparable assessments of grade and trend, thereby providing increased confidence in the content of successive State of the Environment reports and robust tracking of state and trends through time.

The ambiguity associated with approaches to, and justification for, many of the assessments reported in the 2011 marine environment report and the lack of direct analysis of datasets that could be referred to, impacted the ability of assessments to be repeated in a robust manner for the 2016 report. This thereby limited direct comparisons in assessments between the two periods and, in some cases substantial changes to assessment grades and estimates of trends between the two reporting periods resulted. Noting this ambiguity, an indicator of the comparability for the assessments undertaken in the 2011 and 2016 reports was introduced to the 2016 report. This thereby provided the reader with direct information on the strength of comparisons and assisted in interpretation of assessments between the two periods. Three grades of comparability were provided based on the data and methods used in the assessment: ‘comparable’ (when both the data and methods were similar), ‘somewhat comparable’ (when the data was similar but the methods differed) and ‘not comparable’ (when both the data and methods differed).

Of the 123 assessments undertaken in the 2016 report, eight were directly comparable, 68 were somewhat comparable, 24 were not comparable and 23 were unable to be compared because they were not previously assessed. The large number of assessments regarded as somewhat comparable resulted predominantly because although datasets available in 2011 were available in 2016, the methods used to

undertake the assessment in 2011 were unknown.

The 2011 report introduced some consideration of uncertainty in assessments undertaken, using three grades of what was termed 'confidence' that were based on the evidence available and general consensus. These consisted of the categories 'adequate high quality evidence and high level of consensus', 'limited evidence or limited consensus' and 'evidence and consensus too low to make an assessment'. This was provided in a graphical format thereby providing an easily interpretable representation of the certainty assigned to assessment grades and tends. This concept was further built on in the 2016 report with an additional two grades included, providing the reader with finer detail as to the uncertainty associated with each assessment. The two new grades of confidence provided included 'somewhat adequate' where there was either adequate high quality evidence or high level of consensus (but not both) and 'very limited' where there was both limited evidence and limited consensus.

Where values of confidence could be compared between 2011 and 2016, confidence in grade assigned improved across 31 assessments, did not change for 43 assessments and declined for seven assessments. Confidence in trend assigned improved for 36 assessments, did not change for 24 assessments and declined for 21 assessments. These changes suggest that although there have been some improvements in understanding of the marine environment, the pressures impacting it and the effectiveness of management responses, for many components understanding has not changed over the last five years. Most (89%) of the declines in confidence were associated with reassigning confidence categories from 'limited evidence or limited consensus' to either 'very limited' or 'evidence and consensus too low to make an assessment', suggesting that the assessments made in 2011 may have been overly optimistic in the degree of confidence in assigning a grade.

The 2016 marine environment report, for the first time, incorporated Indigenous knowledge on the marine environment, including direct input from Indigenous researchers and community groups. More than 150 Indigenous clan groups along the Australian coastline continue a longstanding connection with sea Country, leading to traditional use of marine resources across a large area of Australia. Traditional use of marine resources (fishing, collecting, hunting and gathering) is part of Aboriginal and Torres Strait Islander peoples' cultures, customs and traditions. This use of resources satisfies personal, subsistence or communal needs and is essential for the health and wellbeing of Indigenous coastal people in Australia [13,22,79]. Reporting on these activities and changes through time therefore constitute an important component of reporting of the marine environment. It also allows for important knowledge gaps and capacity building requirements in regards to community monitoring and management of traditional resources to be identified. Involvement in the 2016 report represents a first step in ongoing input by Traditional Owners to reporting on the marine environment under the SoE framework.

5. Improving future assessments

The modifications made to and additions included in the 2016 marine environment report represent a number of steps aimed at strengthening the report and addressing some of the limitations of reporting of the marine environment over the previous four reporting cycles (e.g. [81]). There still however remain a number of limitations that could be addressed in future assessments of the marine environment. These include (i) further refocusing of assessments to ensure that assessments are relevant, can be feasibly monitored at the national scale and provide relevant information for use in reporting across the many spatial scales assessments occur at (i.e. state and territory, regional and global scales); (ii) greater standardisation and transparency in assigning appropriate grades for assessments; (iii) enhanced synchronization and information exchange processes for assessments done at the state/territory or regional/global level with the national assessment; (iv) improved data provision; (v) integration of assessments of cumulative impacts and (vii) improved approaches to risk assessments. If addressed, these will substantially improve future state of the environment reporting.

5.1. The relevance of indicators and their use across spatial scales

The number of components or processes that can be identified for monitoring in the marine environment is large, especially among its biological components and therefore monitoring all components is beyond available resources. The accuracy of state of environment reporting will remain limited by the lack of comprehensive long-term monitoring of Australia's oceans. This is not to dismiss the excellent advances in monitoring the physical environment and selected biological aspects that have occurred since the development of Australia's Integrated Marine Observing System [50], however, long term time series for biological components are generally lacking even for some important harvested or protected species. Prioritising what, when and how components of the marine ecosystem are monitored is essential if scientific data are to support the decision making processes undertaken by marine managers within changing and increasingly complicated environments.

The 2016 report contained 123 assessments relating to the marine environment. Although this was a reduction from the 196 included in the 2011 report (see [81]), it still included a number that were clearly identified as not currently being supported with enough information to ascertain a grade or trend, or if they were, how such a trend could be interpreted. For example, methods for the assessment of marine microbial communities and processes were identified as only having recently become available and as a consequence, the development of baselines only just started, thereby precluding an assessment of state and trend. Further in such an environment where data collection and knowledge is at such an early stage, even expert opinion provided by those knowledgeable in the relevant field is inconclusive. While it can be argued that it is just as important to identify components of the marine environment for which information is lacking as it is to report on those components of the marine environment there are information available (particularly in the case of key system attributes), this suggests that some reconsideration of indicators for supporting the reporting framework and its objectives is needed. Further, reporting under global and regional agreements or conventions (e.g. the Aichii targets and Sustainable Development Goals) is increasingly requiring assessments against a number of indicators be provided by signatories. There is therefore an opportunity for assessments undertaken at the national level to be aligned in such a way that efforts are integrated and thereby support such reporting processes. As the impacts of climate change continue to increase, therefore necessitating difficult choices between mitigation, restoration and enhancement, the requirement for comprehensive information on the marine environment is only going to increase.

An outline for the monitoring of marine biodiversity based on identifying the informative links between values and pressures has been developed for the Australian marine environment (see [31]). This process could support reporting and evaluation of the marine environment necessary to inform ongoing assessment of the marine environment at the national level, including its response to cumulative impacts. It would also allow for reporting to clearly acknowledge the interconnectivity between components of the Australian environment (e.g. the interfaces between land, coasts, the marine environment and atmosphere) and allow for direct linkages between assessments undertaken under the various themes of the SoE, something that is formally currently lacking. At present the thematic chapters are produced largely independently with linkages made as the discretion of thematic authors. Identification of an agreed and informative set of indicators would also assist in prioritising components of the marine environment that should be the focus for ongoing consistent monitoring efforts [32].

Global initiatives such as the Global Ocean Observing System (see www.goosocean.org) provide international standards and measurement standards for a set of agreed-to Essential Ocean Variables that can be used to inform decision-making (e.g. [15]). Initial work on developing a set of Essential Environmental Measures for the Australian environment has been initiated (see www.environment.gov.au/science/essential-environmental-measures-australia). At present however, these are limited to a few selected areas and focused on coordination, rather than improving the capacity to take measurements in the first place.

5.2. Processes for the assignment of grade and trend

Datasets available for determining trends over time are often spatially limited, and datasets from different locations often vary in the variables measured and time periods across which data are collected. Further many of the assessments were focused on groups of species, communities and habitats that are spatially dispersed and subject to varying pressures and management responses. Scaling grades and trends from a small number of variables measured at a small number of locations to whole habitats, communities or species groups at a national scale becomes difficult as a result [31] and often requires integrating data driven assessment with expert opinion and inference. Many assessments in the 2016 report therefore incorporated considerable variability and uncertainty and realistically spanned a range of grades (e.g. good to very poor) and/or trends (e.g. improving to deteriorating). Under the framework set up by the 2011 report, assessments had to be assigned to a single value of grade or trend and as a consequence, many grades or trends may appeared to be overly simplistic and did not reflect the range of values at the national scale. Dynamic and more flexible frameworks for capturing the span of states that might apply to a component of the environment would ensure that simplistic interpretations of assessments are avoided and variability in assessments across spatial scales is captured. This might involve conducting assessments of key indicators at sub-national scales (for example that might align with oceanographic features or bioregions), thereby capturing the range of states. Scaling assessments more dynamically would ensure better understanding of pressures and observed impacts on the marine environment and allow for targeting of areas where improvements to management can be focused.

5.3. Access to data

While the lack of information available for conducting assessments can be a result of data and information that has not been collected (usually because of the lack of resources and capacity, for example catches associated with traditional harvesting and recreational fishing), for some it is because data and information are not available; that is data or information streams are collected, but are not made publicly available (e.g. industry and regulatory data, data collected by private consulting companies). Many systems are now available to provide for public access to data, spatial maps, derived data products and information of relevance to environmental assessments both globally and in the Australian region. Examples of these for Australia include the Australian Ocean Data Network (for metadata and data, see https://portal.aodn.org.au/) and the various 'atlases', such as eAtlas (see http://eatlas.org.au/) and the Atlas of Living Australia (see https://www.ala.org.au/). Unfortunately, however, not all data collectors provide their data and associated products publically in a format that supports direct access and use in assessments. This reduces the capacity to analyse and compare data and identify trends. Making relevant data and derived products available in a timely fashion and in formats that support the development and use of efficient and repeatable workflows would allow for the monitoring the footprint of industries over time, provide a better understanding of pressures on the marine environment, support regional assessments of the state of the environment and would also be of use by managers and policy makers in supporting more efficient and effective approvals and licensing (e.g. [77]). Provision of such data in standardised formats could be facilitated by making provision of data collected under science programmes a requirement of public funding and environmental approval processes.

5.4. Integrated approaches to assessments

In general, the sectoral approach to marine management in Australia does not account for the cumulative effects of the activities of different sectors on the environment (a common theme across all 2016 SoE thematic reports), nor potential conflicts between different sectors. Multi-sector integrated approaches to assessing and managing complex ecological systems are widely regarded as necessary [49,52]. The lack of integrated approaches to assessing multiple uses in the marine environment contributes to a continuing lack of capacity to identify and measure multiple impacts, and reduces the potential for coordinated approaches to their management. This is likely to result in a gradual decline in the state of the marine environment, despite appropriate management of the individual pressure, sector or jurisdiction.

A real need exists to identify and define cumulative impacts of activities across sectors and jurisdictions, supported by spatially explicit information on habitats, communities and species groups, human uses, the pressures generated by human uses, and any feedbacks within the system. Providing this integrated scientific knowledge would enable each sector to understand the additional impact of their own activities now and in the future, and where cross-sectoral and cross jurisdictional cooperation is required to produce an improved outcome for the environment (and ultimately, those sectors involved) through coordinated approaches to management of activities (see also Section 3.4). Incorporating integrated approaches to assessments, again would allow for direct linkages between assessments undertaken under the various themes of the SoE and interactions and feedbacks between the varying components of the Australian environment to be recognised and reported on in a comprehensive manner.

Risk assessments currently incorporated into the thematic reports are largely based on best judgement using available information (as outlined in [40]), rather than following a formal risk assessment framework. If the State of the Environment report is to address its aims in identifying areas of concern, and thereby providing useful information for managing the marine environment, it would benefit from the incorporation of a robust approach to risk assessments undertaken (however, also see Section 3.4 in regards to agreed approaches). Ecological risk assessment methods are available to identify known residual risks in a quantitative and often hierarchical framework (e.g. [30,72,34]), and can play a central role in an adaptive management process. Classification of residual risks using such frameworks and testing of risks under a range of potential scenarios would build confidence in assessments of risk, enhance the identification of areas for improved future management effectiveness, and therefore ensure that the report provides relevant information for supporting the development and delivery of tangible and practical risk mitigation pathways [80].

6. Conclusion

The 2011 report on the marine environment was considered by its authors as a landmark in national environmental reporting (see [81]), in its use of a combination of available data and expert advice. Each of the five reports produced to date have made improvements to the way in which the environment is assessed and reported and all have identified that further work needs to be done in improving assessments and frameworks for reporting and therefore, providing relevant information at the national level for decision making. The lack of comprehensive monitoring of the marine environment continues to require the use of expert advice to complete a thorough assessment.

The 2016 report on the marine environment represents the most

recent of these reports and similar to previous reports, has undertaken a number of improvements and identified pathways for ongoing, future improvements to the reporting framework. The most substantial improvement in the 2016 marine environment report has been associated with developing clear processes to gather the best available and independent expert advice to improve the transparency in assessments included in the report and support the robustness of conclusions made from assessments. Improved communication of uncertainties associated with the status and trend of assessments, and comparability with previous assessments has further developed the quality of assessments and laid the foundation for greater comparability going forward. The report identified that although the overall state of the marine environment can be regarded as good, the historical impacts of a number of pressures and ongoing impacts of a number of currently poorly managed pressures have, and are continuing to, deteriorate the state of the environment. Key challenges for the marine environment as we look to the future, particularly in the sustainable management of our marine resources under changing environmental conditions, will require a coordinated, collaborative and dedicated effort involving researchers, government, industry and the Australian community.

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Conflicts of interest

None.

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